Maintenance planning on French military aircraft operations

Franco Peschiera, Alain Haït, Olga Battaïa, Nicolas Dupin

ISAE SUPAERO

June 27, 2018
1 Problem

2 State of the art

3 Model

4 Results

5 Current and next steps

6 References
<table>
<thead>
<tr>
<th>Problem</th>
<th>State of the art</th>
<th>Model</th>
<th>Results</th>
<th>Current and next steps</th>
<th>References</th>
</tr>
</thead>
</table>

Franco Peschiera, Alain Haït, Olga Battaïa, Nicolas Dupin
Maintenance planning on French military aircraft operations
<table>
<thead>
<tr>
<th>Problem</th>
<th>State of the art</th>
<th>Model</th>
<th>Results</th>
<th>Current and next steps</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem</td>
<td>Franco Peschiera, Alain Haït, Olga Battaïa, Nicolas Dupin</td>
<td>ISAE SUPAERO</td>
<td>Maintenance planning on French military aircraft operations</td>
<td>4 / 25</td>
<td></td>
</tr>
</tbody>
</table>
Problem (informally)

Assign both missions and maintenance operations to a fleet of aircraft in order to maximize availability and minimize costs. Missions have fixed start and end times and have particular needs in terms of aircraft and time.
Problem (example)
Problem

- A series of $j \in \mathcal{J}$ tasks are planned along a horizon divided into $t \in \mathcal{T}$ periods. Since all tasks are already scheduled, we know time periods $T_j \subset \mathcal{T}$ in which they will be realized.
Problem

- A series of $j \in J$ tasks are planned along a horizon divided into $t \in T$ periods. Since all tasks are already scheduled, we know time periods $T_j \subset T$ in which they will be realized.
- Each task requires a certain number $r_j$ of resources $i \in I$ which it employs for a time duration defined by $h_j$ in each period.
A series of $j \in J$ tasks are planned along a horizon divided into $t \in T$ periods. Since all tasks are already scheduled, we know time periods $T_j \subset T$ in which they will be realized.

Each task requires a certain number $r_j$ of resources $i \in I$ which it employs for a time duration defined by $h_j$ in each period.

Resources require recurrent preventive maintenance operations since the realization of tasks diminish their remaining usage time.
A series of $j \in J$ tasks are planned along a horizon divided into $t \in T$ periods. Since all tasks are already scheduled, we know time periods $T_j \subset T$ in which they will be realized.

Each task requires a certain number $r_j$ of resources $i \in I$ which it employs for a time duration defined by $h_j$ in each period.

Resources require recurrent preventive maintenance operations since the realization of tasks diminish their remaining usage time.

A maintenance operation takes exactly $m$ periods and cannot be interrupted. It restores the resource’s remaining usage time to exactly $H$ units.
State of the art
State of the art (1)

State of the art (1)

- In Cho (2011), US Army aircraft were assigned daily operations over a year to aircraft in order to minimize the maximum number of maintenances.
State of the art (1)

- **FMP: Flight and Maintenance Planning problem.**
- In Cho (2011), US Army aircraft were assigned daily operations over a year to aircraft in order to minimize the maximum number of maintenances.
- In Kozanidis (2008), Greek aircraft had monthly assignments of maintenances and flight hours in order to maximize the availability and final state of squadrons.
State of the art (1)

- In Cho (2011), US Army aircraft were assigned daily operations over a year to aircraft in order to minimize the maximum number of maintenances.
- In Kozanidis (2008), Greek aircraft had monthly assignments of maintenances and flight hours in order to maximize the availability and final state of squadrons.
- In Verhoeff, Verhagen, and Curran (2015), monthly assignments were done and several objectives were taken into account: availability, serviceability and final state.
State of the art (1)

- In Cho (2011), US Army aircraft were assigned daily operations over a year to aircraft in order to minimize the maximum number of maintenances.
- In Kozanidis (2008), Greek aircraft had monthly assignments of maintenances and flight hours in order to maximize the availability and final state of squadrons.
- In Verhoeff, Verhagen, and Curran (2015), monthly assignments were done and several objectives were taken into account: availability, serviceability and final state.
- In De Chastellux, Dupin, and Bazot (2017), an initial version of the model was done, assigning missions instead of only flight hours.
The present model deals with an heterogeneous fleet, with different standards and capacities.
State of the art (2)

- The present model deals with an heterogeneous fleet, with different standards and capacities.
- Multiple objectives have been incorporated in order to satisfy the French Air Force’s specific needs.
State of the art (2)

- The present model deals with an heterogeneous fleet, with different standards and capacities.
- Multiple objectives have been incorporated in order to satisfy the French Air Force’s specific needs.
- This model also features several improvements in the MIP modelling that permit greater instance sizes.
Model
Model: objective function

\[ \min W_1 m_{max} + W_2 u_{max} \]  \hspace{1cm} (1)
Model: objective function

\[
\text{Min } W_1 m_{max} + W_2 u_{max} \tag{1}
\]

The two components of the objective function: the max number of maintenance and the max number of unavailable aircraft.

\[
\sum_{t' \in T_t} \sum_{i \in I} m_{it'} + N_t \leq m_{max} \quad t \in T \tag{2}
\]

\[
\sum_{t' \in T_t} \sum_{i \in I} m_{it'} + N_t + D_t \leq u_{max} \quad t \in T \tag{3}
\]
Mission's needs and incompatibility of several tasks or maintenance in the same period.

\[ \sum_{i \in \mathcal{I}_j} a_{jti} = R_j \quad \text{for} \quad j \in \mathcal{J}, t \in \mathcal{T}_j \quad (4) \]

\[ \sum_{t' \in \mathcal{T}_t^s} m_{it'} + \sum_{j \in \mathcal{J}_t \cap \mathcal{O}_i} a_{jti} \leq 1 \quad \text{for} \quad t \in \mathcal{T}, i \in \mathcal{I} \quad (5) \]
Model: flow constraints

Time usage of an aircraft depending on the assignment to a task.

\[
r_{ut_{it}} \leq r_{ut_{it-1}} + H_{m_{it}} - \sum_{j \in J_t \cap O_i} a_{ji}H_{j} \quad t = 1, \ldots, T, i \in I
\]  

\[
r_{ut_{i0}} = R_{ut_{i_{init}}} 
\]  

\[
r_{ut_{it}} \geq H_{m_{it}} \quad t \in T, i \in I
\]  

\[
r_{ut_{it}} \in [0, H] \quad t \in T, i \in I
\]  

\[
\sum_{i \in I} r_{ut_{it}} \geq R_{ut_{init}} \quad t = |T|
\]
Model: flow constraints

Elapsed times are treated in the same way but consumption is expressed in time periods.

\[
\begin{align*}
  ret_{it} & \leq ret_{i(t-1)} + Em_{it} - 1 & t = 1, \ldots, T, i \in I \\
  ret_{i0} & = Ret_i^{Init} & i \in I \\
  ret_{it} & \geq Em_{it} & t \in T, i \in I \\
  ret_{it} & \in [0, E] & t \in T, i \in I \\
  \sum_{i \in I} ret_{it} & \geq Ret_{sum}^{Init} & t = |T|
\end{align*}
\]
<table>
<thead>
<tr>
<th>Problem</th>
<th>State of the art</th>
<th>Model</th>
<th>Results</th>
<th>Current and next steps</th>
<th>References</th>
</tr>
</thead>
</table>

**Results**
## Experiments

The following instances were tested:

| id  | $||\mathcal{J}||$ | $||\mathcal{T}||$ | assign | objective | time (s) | bound |
|-----|------------------|------------------|--------|-----------|----------|--------|
| I_0 | 9                | 11               | 310    | 62.0      | 0.7      | 62.0   |
| I_1 | 9                | 21               | 650    | 63.0      | 68.7     | 63.0   |
| I_2 | 9                | 31               | 990    | 63.0      | 3600.1   | 62.0   |
| I_3 | 9                | 41               | 1249   | 64.0      | 3603.9   | 61.7   |
| I_4 | 10               | 11               | 530    | 82.0      | 0.9      | 82.0   |
| I_5 | 10               | 21               | 1070   | 83.0      | 144.0    | 83.0   |
| I_6 | 10               | 31               | 1610   | 83.0      | 3600.1   | 82.0   |
| I_7 | 10               | 41               | 2069   | 84.0      | 3609.1   | 81.8   |
| I_8 | 11               | 11               | 1080   | 139.0     | 530.6    | 139.0  |
| I_9 | 11               | 21               | 2120   | 149.0     | 3600.0   | 139.9  |
Sample solution progress

The analysis of the solution progress for all instances shows that:

- Initial solutions are quite far from the linear relaxation.
Sample solution progress

The analysis of the solution progress for all instances shows that:

- Initial solutions are quite far from the linear relaxation.
- Branching does not improve significantly the lower bound.
Sample solution progress

The analysis of the solution progress for all instances shows that:

- Initial solutions are quite far from the linear relaxation.
- Branching does not improve significantly the lower bound.
The analysis of the solution progress for all instances shows that:

- Initial solutions are quite far from the linear relaxation.
- Branching does not improve significantly the lower bound.

(Progress diagram for instance id=I_7).
Multi-objective (1)

Comparison of two objectives: max availability or maintenance capacity. Different weights were used for the two objectives: $W_1, W_2 \in [0..1]$ with pace of 0.1.
## Multi-objective (1)

Comparison of two objectives: max availability or maintenance capacity. Different weights were used for the two objectives: $W_1, W_2 \in [0..1]$ with pace of 0.1.

![Pareto diagram for instance id=I_5]
Multi-objective (2)

- Analysis for all instances: not many Pareto optimal points available (between two and four).
### Multi-objective (2)

- Analysis for all instances: not many Pareto optimal points available (between two and four).
- The objectives are quite aligned one with the other.
Current and next steps
Current steps

- **Linent objectives**: minimized total number of maintenances with a hard maximum on total maintenances per month.
Current steps

- **Linent objectives**: minimized total number of maintenances with a hard maximum on total maintenances per month.
- **Multiple solvers**: GUROBI, CPLEX, CBC, CPO, CHOCO.
Next steps

- **Try different objective formulations**: availability - maintainability - future state.

Franco Peschiera, Alain Haït, Olga Battaïa, Nicolas Dupin

Maintenance planning on French military aircraft operations
Next steps

- **Try different objective formulations**: availability - maintainability - future state.
- **Break symmetries**: clustering candidates, fixing end availabilities.
## Next steps

- **Try different objective formulations**: availability - maintainability - future state.
- **Break symmetries**: clustering candidates, fixing end availabilities.
- **Add more constraints**: minimal duration of assignments, storage of aircraft.
Next steps

- **Try different objective formulations**: availability - maintainability - future state.
- **Break symmetries**: clustering candidates, fixing end availabilities.
- **Add more constraints**: minimal duration of assignments, storage of aircraft.
- **Compare solvers exhaustively**: to determine when each one can be advantageous.
<table>
<thead>
<tr>
<th>Problem</th>
<th>State of the art</th>
<th>Model</th>
<th>Results</th>
<th>Current and next steps</th>
<th>References</th>
</tr>
</thead>
</table>

References

